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THESIS

THREE-DIMENSIONAL FINITE ELEMENT MODEL
OF A HIGH POWER, LOW FREQUENCY
RING-SHELL FLEXTENSIONAL SONAR TRANSDUCER
by

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December 1992

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93-02448



REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE			
4. PERFORMING ORGANIZATION REPORT NUMBER(S)		5. MONITORING ORGANIZATION REPORT NUMBER(S)	
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School	6b. OFFICE SYMBOL (<i>If applicable</i>) 32	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School	
6c. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000		7b. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (<i>If applicable</i>)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c. ADDRESS (City, State, and ZIP Code)		10. SOURCE OF FUNDING NUMBERS	
		Program Element No	Project No
		Task No	Work Unit Accession Number
11. TITLE (<i>Include Security Classification</i>) THREE-DIMENSIONAL FINITE ELEMENT MODEL OF A HIGH POWER, LOW FREQUENCY RING-SHELL FLEXTENSIONAL SONAR TRANSDUCER			
12. PERSONAL AUTHOR(S) Pinto, Rogerio N. C.			
13a. TYPE OF REPORT Master's Thesis	13b. TIME COVERED From To	14. DATE OF REPORT (year, month, day) December 1992	15. PAGE COUNT 88
16. SUPPLEMENTARY NOTATION The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
17. COSATI CODES		18. SUBJECT TERMS (<i>continue on reverse if necessary and identify by block number</i>) Flexextensional Sonar Transducer, ATILA, Finite Element Model, Low Frequency Active Sonar, Sonar Transducer Modeling	
19. ABSTRACT (<i>continue on reverse if necessary and identify by block number</i>) A three-dimensional finite element model of a high power, low frequency ring-shell flexextensional transducer (Sparton of Canada, Ltd., Model 34A0610 was developed for use with the ATILA code. This transducer model is to be coupled with an analytical acoustic field description in order to model a dense sonar array of US Navy interest. The three-dimensional model was derived from a two-dimensional model provided by the Naval Undersea Warfare Center. Two types of finite-element analyses were performed using ATILA: (1) an in-air modal analysis, in which the eigenfrequencies and eigenmodes are computed, and (2) an in-water harmonic analysis, in which the pressure field at a desired frequency is computed. The frequency of the ring mode computed for the three-dimensional model in the modal analysis was found to be 5 percent higher than the corresponding value for the two-dimensional model. From the harmonic analyses, the maximum sound pressure level on the acoustic axis was found to be 4 dB higher than the manufacturer's measured value and is located at exactly the same frequency.			
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS REPORT <input type="checkbox"/> DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL Prof. S. R. Baker		22b. TELEPHONE (<i>Include Area code</i>) (408) 656-2729	22c. OFFICE SYMBOL PH/Ba

Approved for public release; distribution is unlimited.

Three-Dimensional Finite Element Model of a High Power,
Low Frequency Ring-Shell Flextensional Sonar Transducer

by

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Submitted in partial fulfillment
of the requirements for the degrees of
MASTER OF SCIENCE IN ENGINEERING ACOUSTICS
and
MASTER OF SCIENCE IN ELECTRICAL ENGINEERING
from the

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ABSTRACT

A three-dimensional finite element model of a high power, low frequency ring-shell flexextensional transducer (Sparton of Canada, Ltd. Model 34A0610 [Ref. 1]) was developed for use with the ATILA code [Ref. 2]. This transducer model is to be coupled with an analytical acoustic field description in order to model a dense sonar array of US Navy interest [Ref. 3].

The three-dimensional model was derived from a two-dimensional model provided by the Naval Undersea Warfare Center [Ref. 4]. Two types of finite-element analyses were performed using ATILA: (1) an in-air modal analysis, in which the eigenfrequencies and eigenmodes are computed, and (2) an in-water harmonic analysis, in which the pressure field at a desired driving frequency is computed. The frequency of the ring mode computed for the three-dimensional model in the modal analysis was found to be 5 percent higher than the corresponding value for the two-dimensional model. From the harmonic analyses, the maximum sound pressure level on the acoustic axis was found to be 4 dB higher than the manufacturer's measured value and is located at exactly the same frequency.

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ACKNOWLEDGMENTS

I would like to thank Professor Steven Baker for his outstanding guidance, encouragement, support and dedication, Professor Ron Pieper for his recommendations and thesis revisions, and Professor Bryan Wilson for inviting me to do this work, for teaching me the basics of sonar transducer theory and design, for doing the final thesis revision, and for transmitting to me an incomparable example of complete dedication to the education and research causes.

Special thanks are due to Doctor Bernard Hamonic, from l'Institut Superieur d'Electronique du Nord in France, for his assistance with the ATILA code and finite element modeling, to John Blottman, from Naval Undersea Warfare Center, New London, for providing the Sparton ring-shell two-dimensional model, and to Sparton of Canada Ltd. for permitting the publication of this work without restrictions.

Gratitude is also expressed to my colleague Major Tay Tiong Beng, from Republic of Singapore Navy, for doing some drawings and for his assistance with the word processor.

Finally a very special thanks to my wife Vera for typing this thesis, for her encouragement, and for her understanding.

I. INTRODUCTION

The direction of active sonar surveillance systems is toward lower frequencies, requiring arrays of large, high power transducers. The successful design and operation of such arrays requires the ability to predict reliably their performance.

To this end, Professor S. R. Baker of the Physics Department, and Professors D. R. Canright and C. L. Scandrett from the Mathematics Department of the Naval Postgraduate School have established a research program with the goal of developing the means to predict the performance of arbitrarily dense, volumetric active sonar arrays [Ref. 3]. The approach used is based on the T-matrix method, which has been successfully applied to solve multiple scattering problems [Ref. 5]. In the present application, the acoustic field external to an arbitrary collection of radiators (here a radiator is a transducer surrounded by fluid to some arbitrary radius) is represented as a superposition of free-space radiation eigenfunctions (spherical harmonics). For each individual radiator a transition matrix, or T-matrix, is computed, which relates the expansion coefficients of outgoing waves to those of incoming waves and the driving

voltage. This requires the results of two harmonic finite element analyses, the free-field radiation problem and the single element scattering problem. Ultimately, the T-matrix of the total configuration, relating the far-field pressure to the driving voltage applied to each element, is obtained in terms of the T-matrix of the individual elements and translation matrices (of the spherical functions) that depend on the distance between and relative orientation of pairs of elements.

This thesis is concerned with the application of the finite-element code "ATILA", developed at the Institut Supérieur d'Electronique du Nord (Lille, France) [Ref. 2] to provide a three-dimensional model of a low frequency flexextensional transducer of US Navy interest, the Model 34A0610 "ring-shell" transducer, manufactured by Sparton of Canada, Ltd. [Ref. 1], illustrated in Fig. 1. This transducer was used for proof of principle tests of the so-called "billboard" array concept, which is illustrated in Fig. 2. The results of harmonic radiation and scattering analyses performed using ATILA with the three-dimensional model will be used to generate the single-element T-matrix for this transducer, and so enable the billboard array to be modeled using the modified T-matrix method. The solution of the radiation problem is described in this thesis. The solution of the scattering problem can not be performed at this time. It will be performed using the same three-dimensional model as

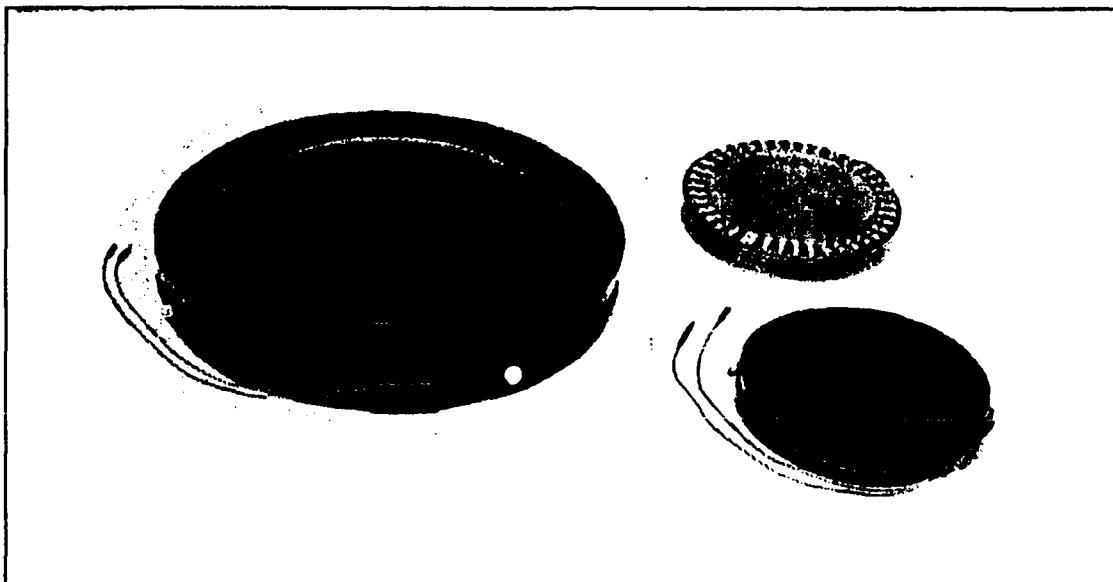


Figure 1 Sparton Flextensional Transducers. From Ref. 1.

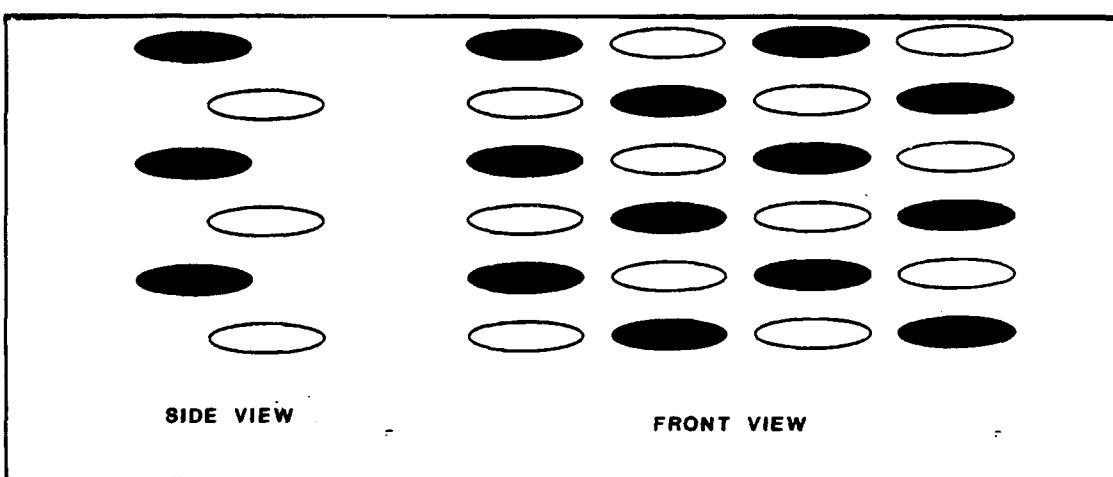


Figure 2 "Billboard" Array Concept.

for the radiation problem as soon this capability is available in ATILA.

A two-dimensional (axisymmetric) model of the ring-shell transducer was developed by the Naval Undersea Warfare Center [Ref. 4]. This model contains 285 elements, 825 nodes, and 1026 degrees-of-freedom. However, an axisymmetric model is not sufficient for modeling a dense array, since all modes of vibration (symmetric and anti-symmetric) can be excited by the incoming pressure field generated by neighboring transducers. A three-dimensional model is necessary.

A three-dimensional model is considerably more complex and requires far more computational time and computer memory. There is, however, a limit of 3000 degrees-of-freedom imposed by our version of the ATILA code. This limitation means that it is not feasible to obtain a three-dimensional model of the ring-shell transducer by a simple rotation of the axisymmetric model about its axis of symmetry. Instead, a simplified three-dimensional model with an acceptable engineering accuracy was pursued.

The remainder of this thesis is divided into six chapters. Chapter II describes the theory involved with the finite element analysis of piezoelectric transducers. Chapter III describes the transducer in question. Chapter IV discusses finite element model design considerations and the characteristics of the three-dimensional model. Chapter V presents and discusses the results of in-air modal analyses

and in-water harmonic analyses. Chapter VI presents the conclusions. Appendix A contains a copy of the input data file for the most refined mesh used in the harmonic analyses.

II. THEORY

A. FINITE ELEMENT ANALYSIS, THE ATILA CODE

The application of finite element analysis (FEA) to solve boundary value problems consists of the transformation of the governing differential or integral equation(s) into a multi-nodal matrix equation, the solution of which represents the discretized solution of the problem. There are many techniques to obtain a finite element formulation [Refs. 6,7,8,9].

ATILA is a finite element code developed at Institut Supérieur d'Electronique du Nord (ISEN) in France for the analysis of underwater transducers. It utilizes the variational formulation of the finite element problem [Refs. 10,11,12,13,14].

ATILA uses quadratic isoparametric elements. Isoparametric means the same polynomial (quadratic) is used to interpolate both geometry and field variation.

ATILA has 46 different types of elements. There are shell, plate, transition, spring, trilaminar, and two- and three-dimensional isoparametric elements of various geometries. It is possible to model elastic, piezoelectric, magnetostrictive, magnetic and composite materials, fluids, solid-fluid interfaces, and radiation dampers.

ATILA can perform: (1) static analyses, (2) modal analyses, which correspond to a free vibration problem, where the eigenfrequencies and eigenmodes are computed, and (3) harmonic analyses of radiation or scattering problems, which correspond to a forced vibration problem, the excitation being the voltage applied across the electrical terminals of the transducer or external forces applied to the nodes.

B. HARMONIC ANALYSIS OF A RADIATING PIEZOELECTRIC TRANSDUCER

This problem is governed by the equations of motion in the elastic and piezoelectric structures, by Poisson's Equation in the piezoelectric structures, and by Helmholtz's Equation in the fluid. Appropriate boundary conditions are defined, both on the solid-fluid interface and over the external fluid boundary, which must simulate the appropriate radiation condition.

The solid equation of motion is given by [Refs. 13,18,19]:

$$\rho \frac{\partial^2 u_i}{\partial t^2} = \frac{\partial \sigma_{ij}}{\partial x_j} \quad (1)$$

where ρ is the solid material density, u is the displacement vector, t is time, $[\sigma]$ is the stress tensor, and x_j is a coordinate direction. Here i and j can be 1, 2 and 3, and the Einstein notation is used, where summation is implied over repeated indices in the same term.

Poisson's Equation is given by [Refs. 13,18,19]:

$$\frac{\partial D_i}{\partial x_i} = 0 \quad (2)$$

where D is the electric displacement vector and x_i is a coordinate direction; i can be 1, 2 and 3.

The linearized, lossless Helmholtz Equation for the propagation of sound in fluids is given by [Ref. 15]:

$$\nabla^2 p - \frac{1}{c^2} \frac{\partial^2 p}{\partial t^2} = 0 \quad (3)$$

where ∇^2 is the three-dimensional Laplacian operator, p is the acoustic pressure, and t is time.

In piezoelectric materials the stress tensor and the electric displacement vector can be related to the strain tensor and the electric field vector and its material properties using the following constitutive equations, which neglect magnetic and pyroelectric effects [Refs. 13,18,19]:

$$\sigma_{ij} = C^E_{ijkl} S_{kl} - e_{kij} E_k \quad (4)$$

$$D_i = e_{ikl} S_{kl} + \epsilon^S_{ij} E_j \quad (5)$$

where $[\sigma]$ is the stress tensor, $[S]$ is the strain tensor, E is the electric field vector, D is the electric displacement

vector, $[c^E]$ is the constant electric field elastic stiffness tensor, $[e]$ is the piezoelectric tensor, and $[\epsilon^S]$ is the constant strain dielectric tensor; i , j , k and l can be equal to 1, 2 and 3.

Ultimately the solution is desired in terms of displacements and electric potentials. To this end the following two equations from elasticity and electricity, respectively, are used [Refs. 13,18,19]:

$$S_{ij} = \frac{1}{2} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \quad (6)$$

$$E_i = - \frac{\partial \Phi}{\partial x_i} \quad (7)$$

where $[S]$ is the strain tensor, u is the displacement vector, x_i is a coordinate direction, E is the electric field vector and Φ is the electrical potential; i and j can be equal to 1, 2 and 3.

The boundary conditions and prescribed excitations at each node can be defined either by a displacement or an applied force, an electrical potential or an electrical charge, or an acoustic pressure.

In ATILA, the previous seven equations are transformed into the following matrix equation [Refs. 2,11,12,14] :

$$\begin{vmatrix} [K_{uu}] - \omega^2 [M] & [K_{u\Phi}] & -[L] \\ [K_{u\Phi}]^T & [K_{\Phi\Phi}] & [0] \\ -\rho^2 C^2 \omega^2 [L]^T & [0]^T & [H] - \omega^2 [M_1] \end{vmatrix} \begin{pmatrix} \mathbf{U} \\ \mathbf{\Phi} \\ \mathbf{P} \end{pmatrix} = \begin{pmatrix} \mathbf{F} \\ -\mathbf{q} \\ \rho C^2 \mathbf{\Psi} \end{pmatrix} \quad (8)$$

where the variables are defined as:

- \mathbf{U} : vector of the nodal values of the components of the displacement field,
- Φ : vector of the nodal values of the electrical potential,
- \mathbf{P} : vector of the nodal values of the pressure field,
- \mathbf{F} : vector of the nodal values of the components of the externally applied forces,
- \mathbf{q} : vector of the nodal values of the externally applied electrical charges,
- Ψ : vector of the nodal values of the integrated normal derivative of the externally applied pressure field (proportional to the externally applied flux),
- $[K_{uu}]$: stiffness matrix,
- $[K_{u\Phi}]$: piezoelectric matrix,
- $[K_{\Phi\Phi}]$: dielectric matrix,
- $[M]$: consistent mass matrix,
- $[H]$: fluid (pseudo-) stiffness matrix,

$[M_1]$: consistent fluid (pseudo-) mass matrix,
 $[L]$: coupling matrix at the fluid structure interface,
 $[0]$: zero matrix,
 ω : angular frequency,
 ρ : fluid density,
 c : fluid sound speed,

and the superscript T represents the matrix transpose.

The results of this analysis for each input frequency are the complex displacement, rotation, and electrical potential fields at each transducer node, the complex pressure field at each fluid node, and the complex electrical impedance and admittance.

C. MODAL ANALYSIS OF A PIEZOELECTRIC TRANSDUCER

This problem is governed by the equations of motion in the elastic and piezoelectric structures, and by Poisson's Equation in the piezoelectric structures. The matrix equation governing this problem is easily obtained from that described in the previous section. In a modal analysis there is no fluid and there are no external forces applied (the natural boundary conditions), so the third row and column of Eq. (8) become irrelevant, and F is replaced by 0, resulting in

$$\begin{vmatrix} [K_{uu}] - \omega^2 [M] & [K_{u\Phi}] \\ [K_{u\Phi}]^T & [K_{\Phi\Phi}] \end{vmatrix} \begin{pmatrix} \sigma \\ \Phi \end{pmatrix} = \begin{pmatrix} 0 \\ -q \end{pmatrix} \quad (9)$$

where the elements are as defined in Eq. (8).

In this equation the resonance condition, which corresponds to the electrical short-circuit condition, is obtained by setting $\Phi=0$. The anti-resonance condition, which corresponds to the electrical open-circuit condition, is obtained by setting $q=0$.

The results of this analysis are the eigenfrequencies and eigenmodes. The maximum number of modes, which must be specified by the user, is 100.

III. TRANSDUCER DESCRIPTION

The transducer modeled in this research project is the Model 34A0610 manufactured by Sparton of Canada, Ltd. [Ref. 1]. It is a depth-compensated, high power, low frequency type V flextensional transducer (so-called "ring-shell"). A cutaway view is shown in Fig. 3 [Ref. 1]. The motor element consists of a set of 144 plates of thickness-poled lead zirconate titanate ceramic of dimensions 8x8x1 cm separated by 72 steel wedges, arranged in a 0.8 m diameter ring [Ref. 4]. The ceramic plates are connected electrically in parallel and effectively poled tangentially. One ST 4340 steel thin shell (a spherical section) is fastened to each ring planar surface. The ring is wrapped on the outside by a fiberglass belt, which provides a compressive stress of 25-40 MPa [Ref. 4].

The main operational characteristics of the transducer are [Ref. 1]:

- a. Resonance Frequency, which corresponds to the maximum voltage response in water - 610 Hz;
- b. Source Pressure Level, which corresponds to the effective pressure on the acoustic axis, at resonance - 213 dB re 1 μ Pa at 1 meter (driven by 3000 volts rms);

- c. Efficiency, which is the ratio of the output acoustic power to the input electric power - 90 percent at resonance, 65 percent at the -6dB points;
- d. Operational Depth, which corresponds to the maximum depth where the performance of the transducer is not compromised - exceeds 400 m.

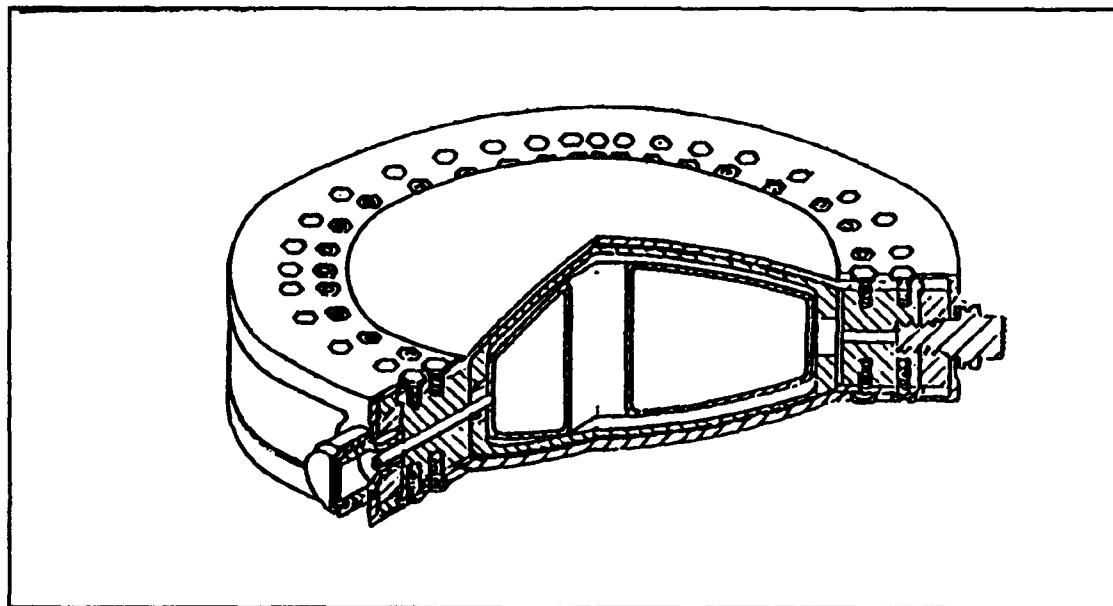


Figure 3 Cutaway view of the transducer. From Ref. 1.

IV. THREE-DIMENSIONAL MODEL

A. INTRODUCTION

As mentioned in Chapter I, the performance modeling of a dense sonar array by means of the T-matrix method requires the computation of the radiation and scattering of an individual transducer. This can be accomplished very accurately using finite element analysis (FEA); however a three-dimensional (3-D) model must be employed.

A 3-D finite element model of a flexextensional transducer has an inherent complexity compared to a corresponding 2-D model. The major limitation is the number of degrees of freedom (DOF) available, which depends upon the computer used. A simple transformation of the available 2-D model into a 3-D model would represent roughly more than 10000 DOF just for the solid structure. This already exceeds the maximum allowed degrees of freedom on the MICROVAX VMS system, where the ATILA code is installed, and so is not feasible.

Consequently, the objective of this research became to develop the simplest 3-D model of the Sparton ring-shell transducer that could reproduce, within acceptable error limits when compared with experimental data, its pertinent electroacoustic properties.

B. CHARACTERISTICS OF THE MODEL

1. MATERIAL PROPERTIES

All material properties are included on the first page of Appendix A. The format is according to the ATILA user's manual [Ref. 2].

a. *Piezoelectric ceramic*

As described before, the transducer has 144 tangentially poled lead zirconate titanate ceramic plates separated by 72 steel wedges, arranged in a 0.8 m diameter ring. An illustration of this arrangement is shown in Fig. 4. In order to simplify the model, a homogeneous ring with material properties equivalent to an adequate combination of the ceramic and steel was used. This is illustrated in Fig. 5. These properties were provided to us by Blottman who obtained them from McMahon [Ref. 4]: "The smeared material properties were obtained by McMahon and Armstrong through in-air measurement of the segmented ring during various stages of assembly. The measurements consist of the resonance and anti-resonance frequencies and the electrical capacitance." These properties take into consideration the compression given by the fiberglass wrapping. The given ceramic properties include losses, but as will be noted later, the results of harmonic analyses that included losses yielded a pressure field about 100 times smaller than the corresponding experimental results.

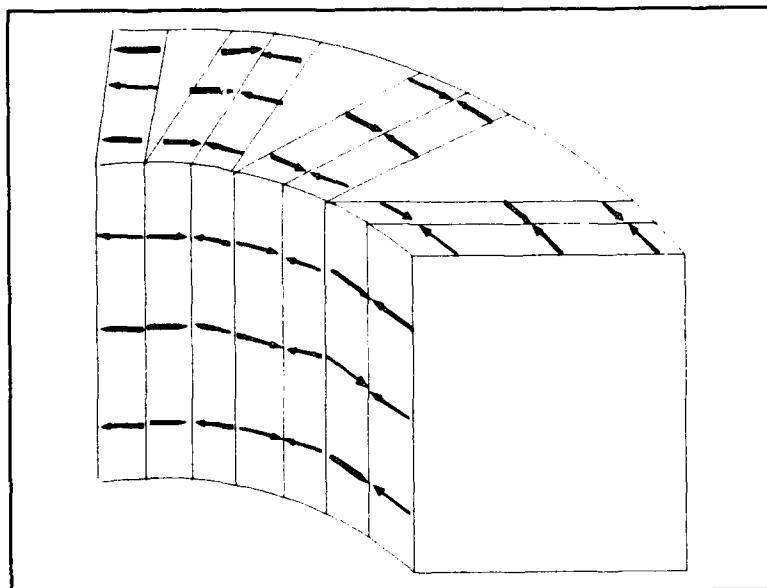


Figure 4 Original ring-shell arrangement.

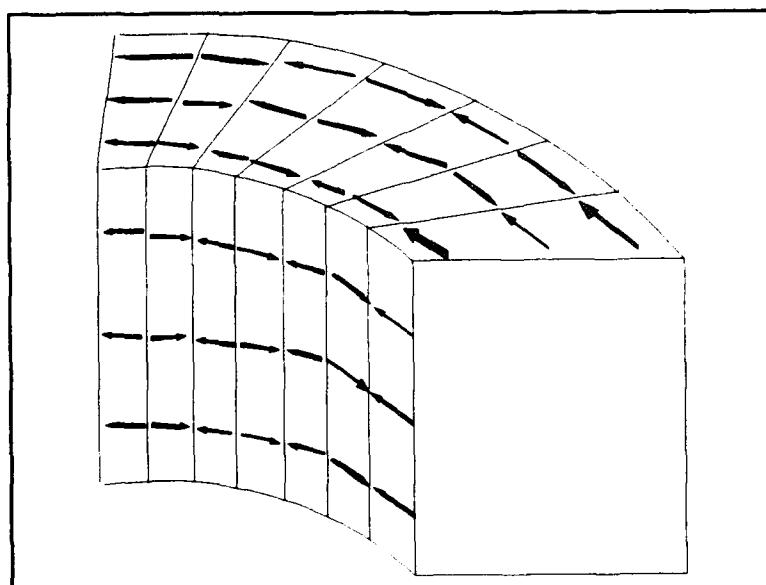


Figure 5 Smeared ring-shell arrangement.

To model the transducer with its actual polarization requires the use of a very large number of elements because of the mesh design requirements; therefore the polarization was switched to an equivalent axially-poled ring. The transformation of the polarization is obtained by a suitable exchange of the elastic, piezoelectric and dielectric tensors. The procedure is outlined in the ATILA user's manual [Ref. 2].

Note that the ATILA manual describes the transformation from tangential polarization to radial polarization, which is not the present case. An axial orientation was chosen here rather than a radial orientation in order to simplify the application of electrical boundary conditions. Because of this modification the results of harmonic analyses have to be modified as follows: (1) divide the displacement and pressure fields by the ratio of the circumferential length of a "smeared" piezoelectric element (which is equal to 1/144 of the the ring circumferencial length) to its height, and (2) multiply the electrical impedance by the square of the same ratio. In the present case this ratio is 0.1958.

b. Fiberglass

To simplify the model the fiberglass wrapping was modeled as an equivalent shell; otherwise a considerable number of additional elements would be required.

c. Shells

Their actual material properties were used.

2. TYPES OF ELEMENTS

The following quadratic isoparametric elements, which are described in the ATILA User's Manual [Ref. 2], were used:

TABLE 1

Region	Element	Geometry
Piezoelectric ring	HEXA20P	20-node hexahedron
Shells	SHEL06C	6-node triangle
Fiberglass wrapping	QUAD08E	8-node quadrilateral
Interface solid-fluid	TRIA12I	2x6-node triangle
Interface solid-fluid	QUAD16I	2x8-node quadrilateral
Fluid	PRISM15F	15-node triangular base prism
Fluid	HEXA20F	20-node hexahedron
Radiation surface	TRIA06R	6-node triangle
Radiation surface	QUAD08R	8-node quadrilateral

3. CONSTRAINTS ON MESH DESIGN

Design of the mesh was guided by the following constraints:

a. Aspect ratio [Ref. 2]

The aspect ratio of each element should be not greater than 3, although 4 is considered an acceptable, though less conservative, value.

b. Internal angles [Ref. 2]

The internal angles of each elements should be not smaller than 45 degrees and not greater than 135 degrees, although 30 degrees and 150 degrees are considered, respectively, acceptable, though less conservative, values.

c. Element size [Ref. 2]

As ATILA utilizes quadratic interpolation functions, the size of each element must be not greater than one fourth of a wavelength at the highest frequency of interest.

d. Interelement compatibility

The mesh should be built in such a way that adjacent elements have adjoining sides with collocated nodes to ensure accurate interpolation at their interfaces.

e. Coupling of shell elements to solid elements

Unlike two-dimensional elements, ATILA does not provide three-dimensional transition elements to match solid (piezoelectric) and shell three-dimensional elements. To

perform harmonic analyses it was necessary to delete the rotational degrees-of-freedom (DOF) for the piezoelectric nodes, which means that a clamped condition, which is not quite realistic, was assumed between the shell and the piezoelectric ring. As will be seen later, as the mesh becomes more and more refined, this assumed boundary condition becomes less and less significant.

f. Radiation boundary elements [Ref. 2]

For in-water harmonic analyses (radiation problems) the fluid mesh outer limit must be spherical. This is required by the radiation elements available in the ATILA code. ATILA offers so-called monopole and dipole radiation damping elements. The latter includes not only the monopole term of the radiated field multipolar expansion, but also the dipole term. Dipolar damping elements were selected to terminate the fluid mesh because they provide a more accurate solution than the monopolar damping elements for the mesh employed.

A fluid mesh outer limit radius greater than the far-field distance is desirable to compute the acoustic source pressure level and to compare computed and measured acoustic pressure data. The boundary was placed at a radius R equal to 0.72 m from the transducer's acoustical center, which is beyond 3.5 times the far-field limit of the equivalent piston-like source at the resonance frequency [Ref. 16].

4. FINAL MESH DESIGNS

With the above constraints one coarse mesh was designed for each type of analysis to be performed: in-air modal and in-water harmonic. An in-air modal analysis requires only the transducer to be modeled. An in-water harmonic analysis requires in addition the surrounding fluid to be modeled. The transducer coarse mesh consists of 12 shell elements and 8 solid elements, totaling 250 DOF, and is shown in Fig. 6. The total coarse mesh, which includes the fluid, contains in addition, 20 interface elements, 72 fluid elements, and 28 radiating elements, totaling 1330 DOF. This mesh is shown in Fig. 7. Based on these meshes and using the pre-processor mesh generator MOSAIQUE [Ref. 2], two mesh refinements were obtained. The most refined transducer mesh, which is shown in Fig. 8, consists of 40 shell elements and 24 solid elements, totaling 557 DOF. The corresponding total mesh, which is shown in Fig. 9, contains, in addition, 56 interface elements, 176 fluid elements and 72 radiating elements, totaling 2868 DOF. The input data file of this mesh is given in Appendix A.

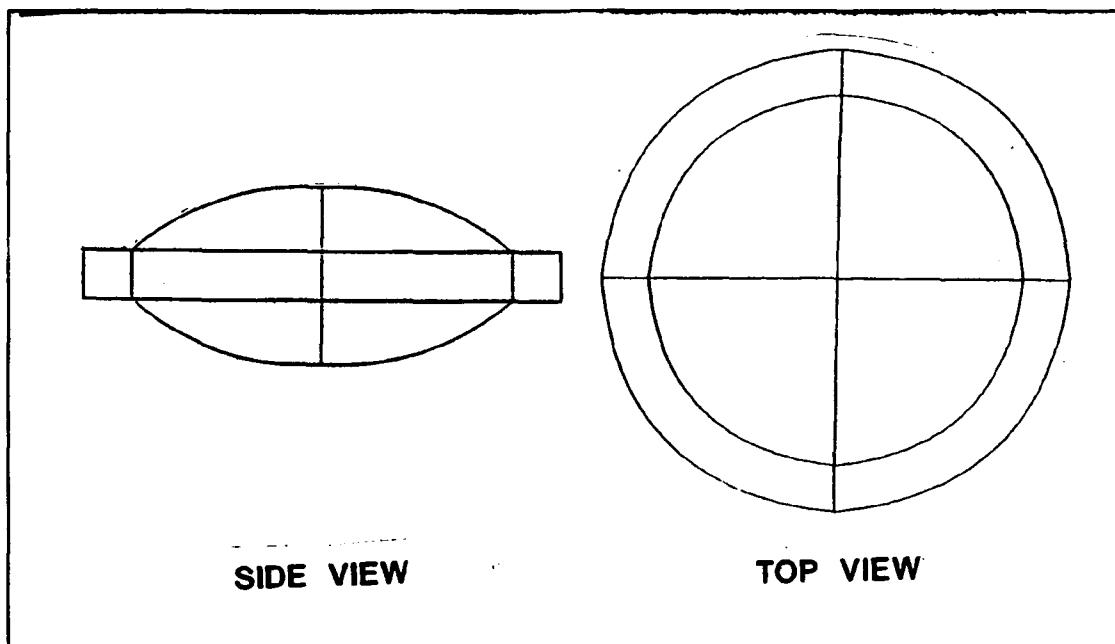


Figure 6 Transducer coarse mesh.

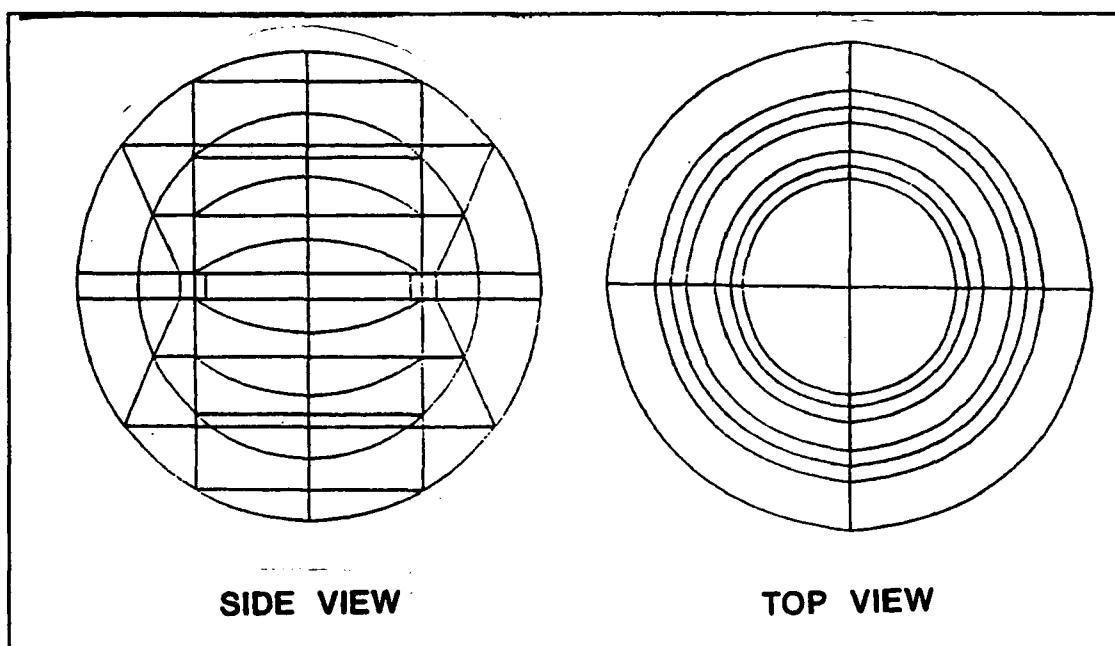


Figure 7 Total coarse mesh.

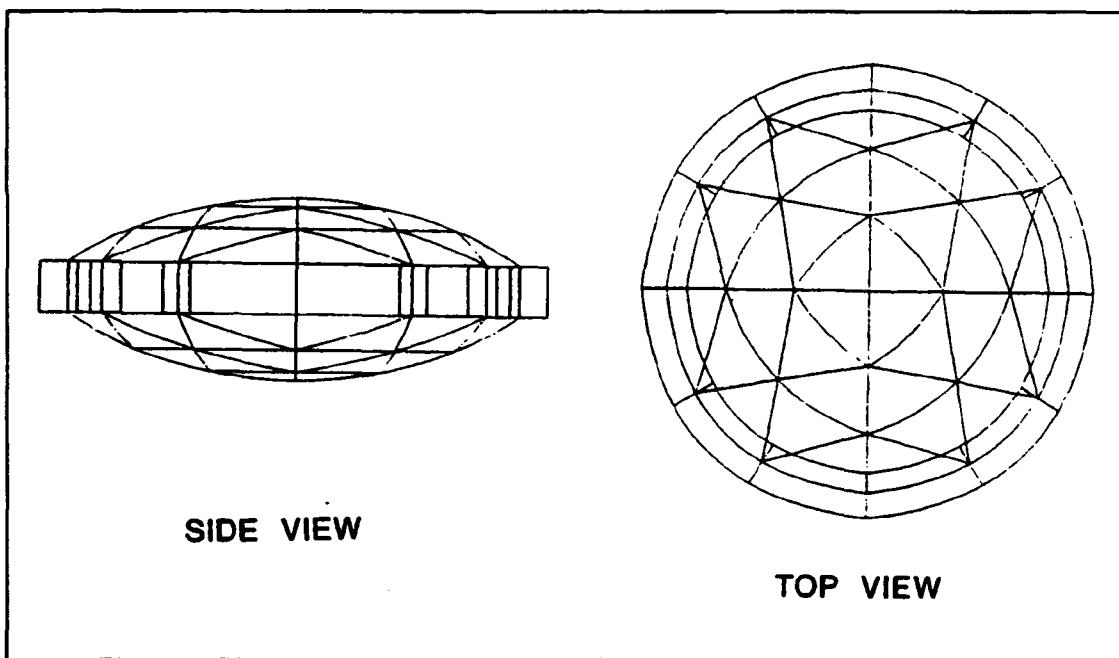


Figure 8 Transducer refined mesh.

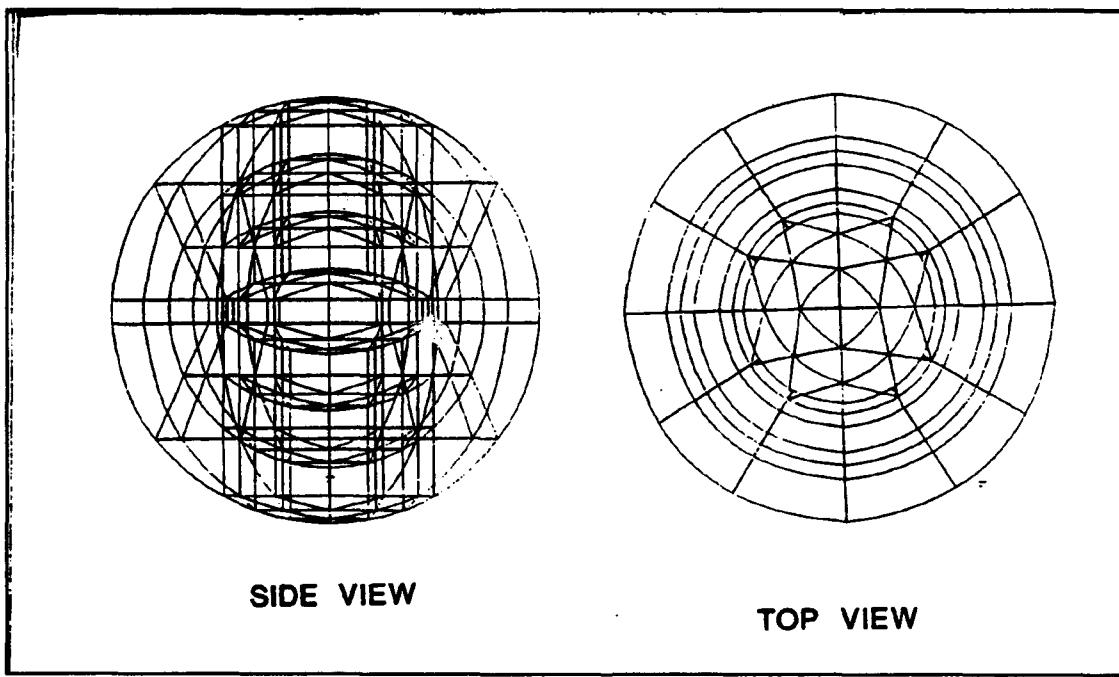


Figure 9 Total refined mesh.

V. RESULTS

A. IN-AIR MODAL ANALYSES

This analysis corresponds to a free vibration problem, where the eigenfrequencies and eigenmodes are computed. Three mesh grades were analysed. For each one, the first twenty eigenfrequencies and eigenmodes were calculated (including the rigid body ones). The following table, which includes the two-dimensional (2-D) model, summarizes some characteristics of each mesh, along with the resonance frequency of the mode of vibration shown in Fig. 10, which is the most important in operation.

TABLE 2

Mesh	Coarse	Inter- mediate	Refined	2-D Model
Nodes	86	202	350	191
Elements	20	56	180	42
DOF	250	730	1330	392
Micro Vax II CPU Time	580 sec	9 hr	24 hr	14 min
Frequency	1746 Hz	1098 Hz	1002 Hz	957 Hz

The dashed lines in Fig. 10 correspond to the rest position; the solid lines correspond to the displaced position. Note the opposite sense of the motion of the ring and shells.

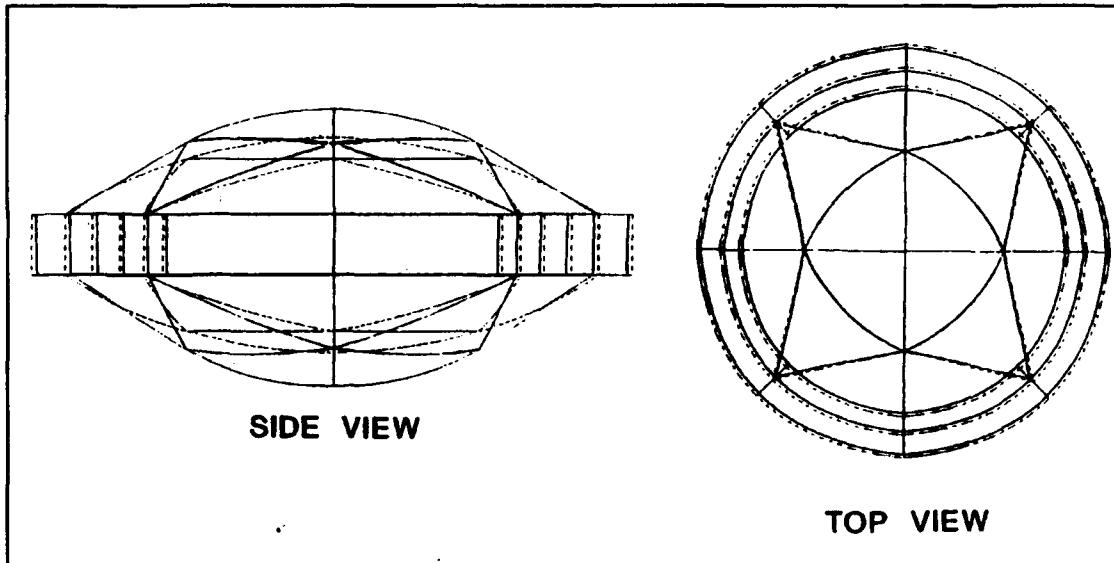


Figure 10 Ring mode of vibration.

A comparison between the results of the ring mode frequency for the more refined 3-D mesh and the 2-D model shows that the first is 5 percent higher than the second. Notice from Table 2 that as the mesh becomes more and more refined, the ring mode natural frequency value approaches more closely the corresponding 2-D model value. This is in part due to the clamped condition between the shell and the piezoelectric ring, which is not quite right, and possibly because of the use of a limited number of elements to describe the shape of the shell.

B. IN-WATER HARMONIC ANALYSES

This analysis corresponds to a forced vibration problem, the excitation being the voltage applied across the electrical terminals of the transducer. Three mesh grades were analysed, now including not only the transducer elements, but the interface, fluid and radiating elements. Internal material losses are not included in this model because the results obtained with such losses included were found to be about 40 dB below the corresponding measured values. The reason for this is not known. It is a problem which appeared only in three-dimensional modeling; no such problem was observed for axisymmetric models. In any case, neglecting internal losses is not a serious deficiency, since radiation losses dominate.

The following table, which includes the two-dimensional model and the manufacturer's measured values, summarizes some characteristics of each mesh along with the maximum sound pressure level (SPL) in dB re $1\mu\text{Pa}$ at a distance of 1m on the acoustic axis when driven by 3000 Vrms at the corresponding frequency.

TABLE 3

Mesh	Coarse	Refined	More Refined	2-D Model	Measured
Nodes	392	972	1696	825	xxxx
Elements	140	360	706	285	xxxx
DOF	557	1501	2868	1026	xxxx
Micro Vax II CPU time	3 hrs	33 hrs	101 hrs	48 min	xxxx
SPL dB re 1 μ Pa	200	209	217	213	213
Frequency Hz	1108	662	610	628	610

The following plot depicts the transmitting voltage response curve obtained by ATILA along with the corresponding manufacturer's data. The model displays a higher peak sound pressure level (SPL) for the primary resonance than the actual transducer. This was expected, since internal material losses were not considered.

It can be observed also from FIG. 11 that the second resonance of the model occurs at a considerably higher frequency than for the actual device. As discussed before, the probable explanation for this is that even the most refined

mesh used is not refined enough to represent the transducer dynamical behavior completely. This is in part due to the clamped condition between the shell and the piezoelectric ring, which is not quite right.

Notice in Table 3 that as the mesh becomes more and more refined, the SPL and resonant frequency values approach more closely the corresponding measured values. An attempt was made to perform a harmonic analysis using a mesh which was more refined (4184 DOF). This was not successful, however; apparently the number of degrees-of-freedom exceeded the limit imposed by our copy of ATILA.

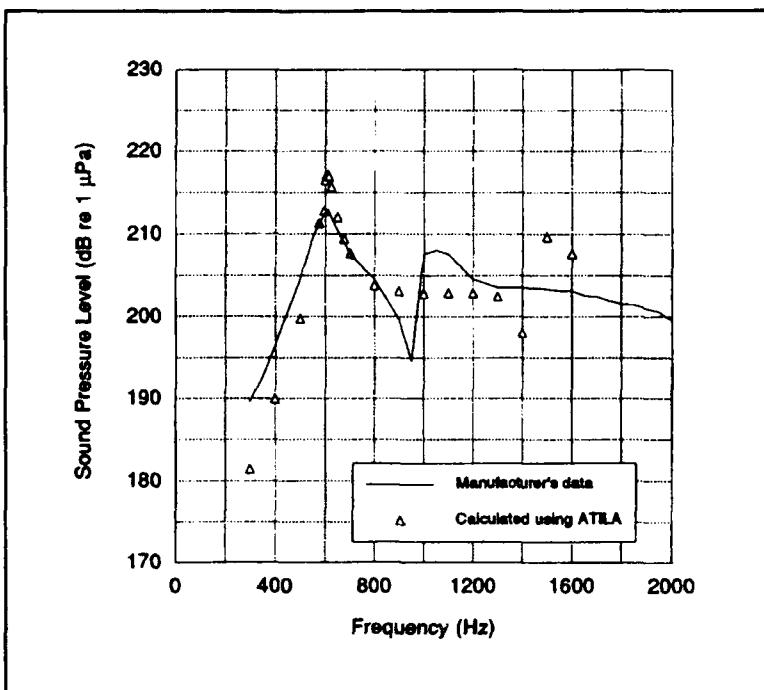


Figure 11 Transmitting voltage response curve at 1m on acoustic axis driven at 3000 Vrms.

Plots of electrical impedance versus frequency and impedance circle for the more refined model are depicted in Figs. 12 and 13, respectively. Finally, electrical admittance versus frequency and the admittance circle are shown in Figs. 14 and 15, respectively.

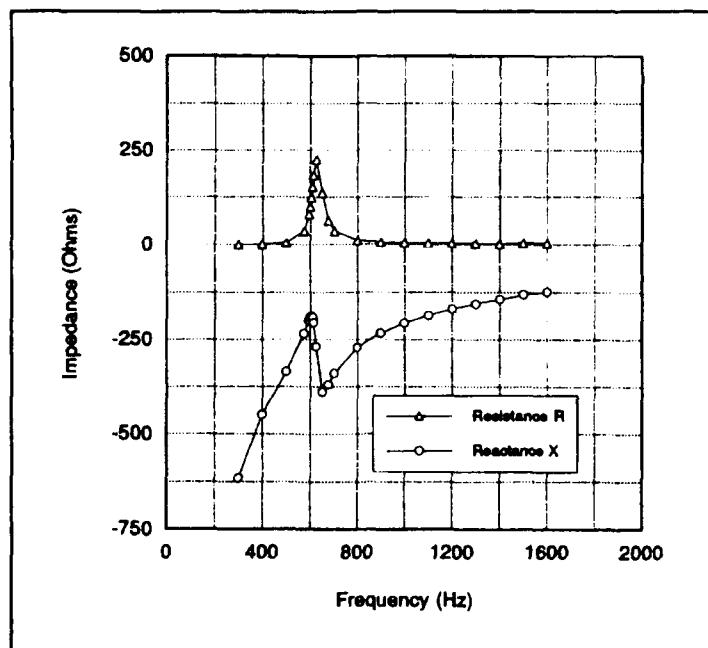


Figure 12 Impedance versus frequency.

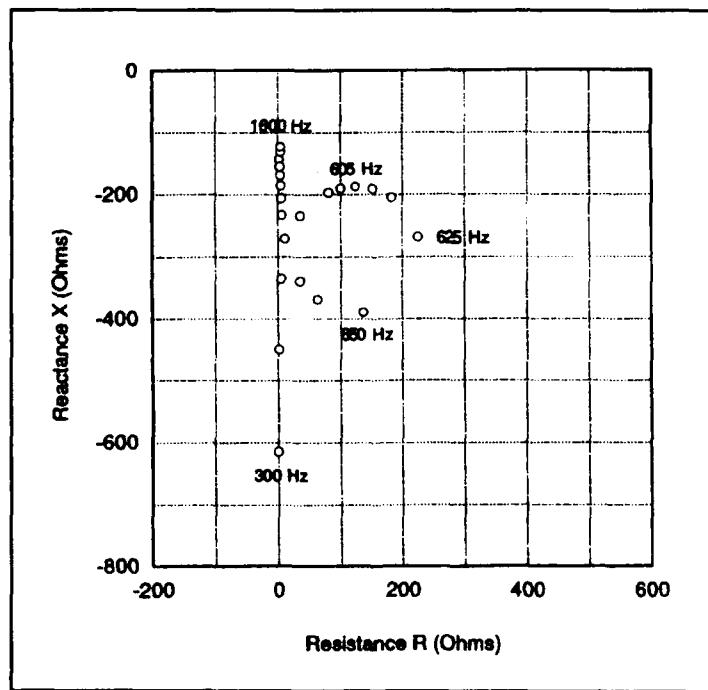


Figure 13 Impedance circle.

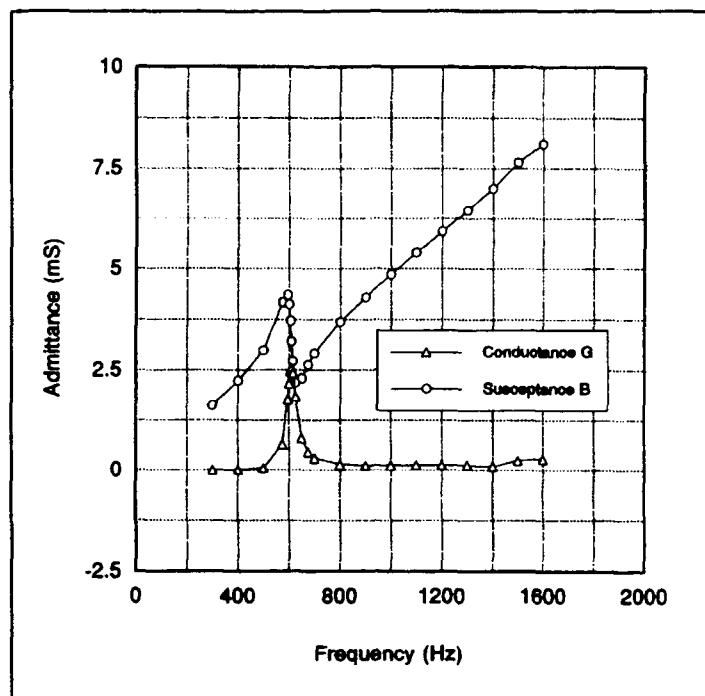


Figure 14 Admittance versus frequency.

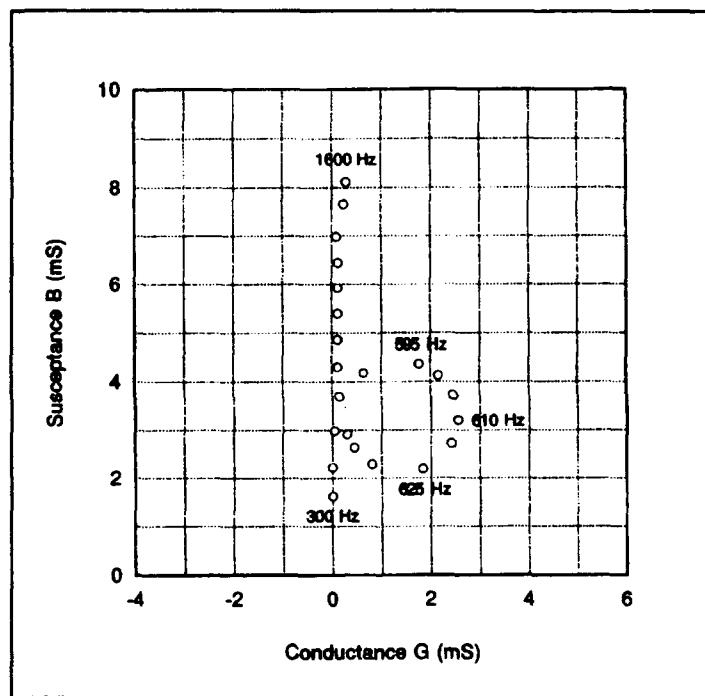


Figure 15 Admittance circle.

VI. CONCLUSIONS

A three-dimensional model of a ring-shell flexensional transducer was built. Although the model includes many necessary simplifications to handle the problem in the available MICROVAX VMS system, the model is successful in obtaining a maximum sound pressure level from the in-water harmonic analyses that differs by 4 dB from the measured value and is located exactly at the same frequency.

The model does not consider internal material losses because the ATILA code was not able to compute accurate results for the three-dimensional model in this case. These difficulties were not encountered with axisymmetric models.

The model was built for the purpose of computing the radiation and scattering properties of the Sparton ring-shell transducer, the results of which are to be combined with an acoustic field model in order to describe the performance of a dense sonar array. Thus far the model has been used to compute the radiation pressure field. It will be used to compute the scattered pressure field when this capability becomes available in ATILA.

APPENDIX A

INPUT DATA FILE

```
* TRANSDUCER:RINGSHELL / TWO STEP REFINED THREE-DIMENSIONAL MESH.  
*  
*=====*  
* MANUFACTURER:SPARTON OF CANADA. *  
* MODEL:34A0610. *  
* IN-WATER HARMONIC ANALYSIS. *  
* WRITTEN BY LCDR ROGERIO PINTO ON NOV,30,1992. *  
*=====*  
*  
SKYLINE REAL  
PRECISION DOUBLE  
RADIATION DIPOLAR  
LCPDDC  
10 ELECPOT PRESSURE THETAX THETAY UX UY UZ  
NLOAD  
40  
FREQUENCY  
1.100E+03 1.200E+03 1.300E+03 1.400E+03 1.500E+03 1.600E+03  
ANALYSIS HARMONIC  
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FICFIBER  
0.645E+09 0.400E+00 0.806E+04  
  
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1  
0.105E-01 *THICKNESS OF SHELLS.  
2  
0.500E-02 *THICKNESS OF FICTITIOUS FIBER WRAPPING.  
3  
0.720E+00 *RADIUS OF FLUID MESH OUTER LIMIT.
```

GEOMETRY POLARIZA CARTESIA

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 6
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 * 172 * -0.40000E-01 0.00000E+00 0.31900E+00
 * 173 * 0.00000E+00 0.27140E+00 0.16506E+00
 * 174 * 0.00000E+00 0.16506E+00 0.27140E+00
 * 175 * 0.00000E+00 0.00000E+00 0.31900E+00
 * 176 * 0.40000E-01 0.28653E+00 0.17427E+00
 * 177 * 0.40000E-01 0.17427E+00 0.28653E+00
 * 178 * 0.40000E-01 0.00000E+00 0.33679E+00
 * 179 * 0.40000E-01 0.30254E+00 0.89872E-01
 * 180 * 0.40000E-01 0.27140E+00 0.16506E+00

*	181	*	0.40000E-01	0.22557E+00	0.22557E+00
*	182	*	0.40000E-01	0.16506E+00	0.27140E+00
*	183	*	0.40000E-01	0.89872E-01	0.30254E+00
*	184	*	0.40000E-01	0.00000E+00	0.31900E+00
*	185	*	-0.40000E-01	-0.11241E+00	0.37841E+00
*	186	*	-0.40000E-01	-0.20646E+00	0.33946E+00
*	187	*	-0.40000E-01	-0.28214E+00	0.28214E+00
*	188	*	-0.40000E-01	-0.33946E+00	0.20646E+00
*	189	*	-0.40000E-01	-0.37841E+00	0.11241E+00
*	190	*	-0.40000E-01	-0.19497E+00	0.32056E+00
*	191	*	-0.40000E-01	-0.32056E+00	0.19497E+00
*	192	*	-0.40000E-01	-0.99897E-01	0.33628E+00
*	193	*	-0.40000E-01	-0.18347E+00	0.30167E+00
*	194	*	-0.40000E-01	-0.25073E+00	0.25073E+00
*	195	*	-0.40000E-01	-0.30167E+00	0.18347E+00
*	196	*	-0.40000E-01	-0.33628E+00	0.99897E-01
*	197	*	0.00000E+00	-0.20646E+00	0.33946E+00
*	198	*	0.00000E+00	-0.33946E+00	0.20646E+00
*	199	*	0.00000E+00	-0.18347E+00	0.30167E+00
*	200	*	0.00000E+00	-0.30167E+00	0.18347E+00
*	201	*	0.40000E-01	-0.11241E+00	0.37841E+00
*	202	*	0.40000E-01	-0.20646E+00	0.33946E+00
*	203	*	0.40000E-01	-0.28214E+00	0.28214E+00
*	204	*	0.40000E-01	-0.33946E+00	0.20646E+00
*	205	*	0.40000E-01	-0.37841E+00	0.11241E+00
*	206	*	0.40000E-01	-0.19497E+00	0.32056E+00
*	207	*	0.40000E-01	-0.32056E+00	0.19497E+00
*	208	*	0.40000E-01	-0.99897E-01	0.33628E+00
*	209	*	0.40000E-01	-0.18347E+00	0.30167E+00
*	210	*	0.40000E-01	-0.25073E+00	0.25073E+00
*	211	*	0.40000E-01	-0.30167E+00	0.18347E+00
*	212	*	0.40000E-01	-0.33628E+00	0.99897E-01
*	213	*	-0.40000E-01	-0.17427E+00	0.28653E+00
*	214	*	-0.40000E-01	-0.28653E+00	0.17427E+00
*	215	*	-0.40000E-01	-0.89872E-01	0.30254E+00
*	216	*	-0.40000E-01	-0.16506E+00	0.27140E+00
*	217	*	-0.40000E-01	-0.22557E+00	0.22557E+00
*	218	*	-0.40000E-01	-0.27140E+00	0.16506E+00
*	219	*	-0.40000E-01	-0.30256E+00	0.89872E-01
*	220	*	0.00000E+00	-0.16506E+00	0.27140E+00
*	221	*	0.00000E+00	-0.27140E+00	0.16506E+00
*	222	*	0.40000E-01	-0.17427E+00	0.28653E+00
*	223	*	0.40000E-01	-0.28653E+00	0.17427E+00
*	224	*	0.40000E-01	-0.89872E-01	0.30254E+00
*	225	*	0.40000E-01	-0.16506E+00	0.27140E+00
*	226	*	0.40000E-01	-0.22557E+00	0.22557E+00
*	227	*	0.40000E-01	-0.27140E+00	0.16506E+00
*	228	*	0.40000E-01	-0.30254E+00	0.89872E-01
*	229	*	0.69986E-01	-0.30439E+00	0.00000E+00
*	230	*	0.69986E-01	-0.27616E+00	-0.93519E-01
*	231	*	0.69986E-01	-0.23160E+00	-0.17072E+00
*	232	*	0.69986E-01	-0.17072E+00	-0.23160E+00
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*	234	*	0.69986E-01	0.00000E+00	-0.30439E+00
*	235	*	0.94876E-01	-0.25064E+00	0.00000E+00
*	236	*	0.94876E-01	-0.21246E+00	-0.87141E-01
*	237	*	0.94876E-01	-0.15796E+00	-0.15796E+00
*	238	*	0.94876E-01	-0.87141E-01	-0.21246E+00
*	239	*	0.94876E-01	0.00000E+00	-0.25064E+00
*	240	*	0.11467E+00	-0.19333E+00	0.00000E+00
*	241	*	0.11467E+00	-0.14521E+00	-0.80763E-01
*	242	*	0.11467E+00	-0.80763E-01	-0.14521E+00
*	243	*	0.11467E+00	0.00000E+00	-0.19333E+00
*	244	*	0.12937E+00	-0.13245E+00	0.00000E+00
*	245	*	0.12937E+00	-0.74386E-01	-0.74386E-01
*	246	*	0.12937E+00	0.00000E+00	-0.13245E+00
*	247	*	0.13897E+00	-0.68008E-01	0.00000E+00
*	248	*	0.13897E+00	0.00000E+00	-0.68008E-01
*	249	*	0.14348E+00	0.00000E+00	0.00000E+00

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 * 1619 * 0.26033E+00 0.67129E+00 0.00000E+00
 * 1620 * -0.26033E+00 -0.67129E+00 0.00000E+00
 * 1621 * 0.26033E+00 -0.67129E+00 0.00000E+00
 * 1622 * -0.71568E+00 0.68008E-01 0.00000E+00
 * 1623 * 0.71568E+00 0.68008E-01 0.00000E+00
 * 1624 * -0.71568E+00 -0.68008E-01 0.00000E+00
 * 1625 * 0.71568E+00 -0.68008E-01 0.00000E+00
 * 1626 * -0.69356E+00 0.19333E+00 0.00000E+00
 * 1627 * 0.69356E+00 0.19333E+00 0.00000E+00
 * 1628 * -0.72000E+00 0.00000E+00 0.00000E+00
 * 1629 * 0.72000E+00 0.00000E+00 0.00000E+00

* 1630 *	-0.69356E+00	-0.19333E+00	0.00000E+00
* 1631 *	0.69356E+00	-0.19333E+00	0.00000E+00
* 1632 *	-0.71568E+00	0.00000E+00	0.68008E-01
* 1633 *	0.71568E+00	0.00000E+00	0.68008E-01
* 1634 *	-0.62664E+00	0.33628E+00	0.99897E-01
* 1635 *	0.62664E+00	0.33628E+00	0.99897E-01
* 1636 *	-0.62664E+00	-0.33628E+00	0.99897E-01
* 1637 *	0.62664E+00	-0.33628E+00	0.99897E-01
* 1638 *	-0.70687E+00	0.00000E+00	0.13245E+00
* 1639 *	0.70687E+00	0.00000E+00	0.13245E+00
* 1640 *	-0.62664E+00	0.30167E+00	0.18347E+00
* 1641 *	0.62664E+00	0.30167E+00	0.18347E+00
* 1642 *	-0.62664E+00	-0.30167E+00	0.18347E+00
* 1643 *	0.62664E+00	-0.30167E+00	0.18347E+00
* 1644 *	-0.69356E+00	0.00000E+00	0.19333E+00
* 1645 *	0.69356E+00	0.00000E+00	0.19333E+00
* 1646 *	-0.55080E+00	-0.39484E+00	0.24025E+00
* 1647 *	0.55080E+00	-0.39484E+00	0.24025E+00
* 1648 *	-0.55080E+00	0.39484E+00	0.24025E+00
* 1649 *	0.55080E+00	0.39484E+00	0.24025E+00
* 1650 *	-0.67575E+00	0.00000E+00	0.25064E+00
* 1651 *	0.67575E+00	0.00000E+00	0.25064E+00
* 1652 *	-0.62664E+00	0.25073E+00	0.25073E+00
* 1653 *	0.62664E+00	0.25073E+00	0.25073E+00
* 1654 *	-0.62664E+00	-0.25073E+00	0.25073E+00
* 1655 *	0.62664E+00	-0.25073E+00	0.25073E+00
* 1656 *	-0.43188E+00	0.49012E+00	0.29809E+00
* 1657 *	0.43188E+00	0.49012E+00	0.29809E+00
* 1658 *	-0.43188E+00	-0.49012E+00	0.29809E+00
* 1659 *	0.43188E+00	-0.49012E+00	0.29809E+00
* 1660 *	-0.62664E+00	0.18347E+00	0.30167E+00
* 1661 *	0.62664E+00	0.18347E+00	0.30167E+00
* 1662 *	-0.62664E+00	-0.18347E+00	0.30167E+00
* 1663 *	0.62664E+00	-0.18347E+00	0.30167E+00
* 1664 *	-0.65344E+00	0.00000E+00	0.30439E+00
* 1665 *	0.65344E+00	0.00000E+00	0.30439E+00
* 1666 *	-0.62664E+00	0.99897E-01	0.33628E+00
* 1667 *	0.62664E+00	0.99897E-01	0.33628E+00
* 1668 *	-0.62664E+00	-0.99897E-01	0.33628E+00
* 1669 *	0.62664E+00	-0.99897E-01	0.33628E+00
* 1670 *	-0.62664E+00	0.00000E+00	0.35458E+00
* 1671 *	0.62664E+00	0.00000E+00	0.35458E+00
* 1672 *	-0.55080E+00	0.24025E+00	0.39484E+00
* 1673 *	0.55080E+00	0.24025E+00	0.39484E+00
* 1674 *	-0.55080E+00	-0.24025E+00	0.39484E+00
* 1675 *	0.55080E+00	-0.24025E+00	0.39484E+00
* 1676 *	-0.43188E+00	0.40736E+00	0.40736E+00
* 1677 *	0.43188E+00	0.40736E+00	0.40736E+00
* 1678 *	-0.43188E+00	-0.40736E+00	0.40736E+00
* 1679 *	0.43188E+00	-0.40736E+00	0.40736E+00
* 1680 *	-0.55080E+00	0.00000E+00	0.46375E+00
* 1681 *	0.55080E+00	0.00000E+00	0.46375E+00
* 1682 *	-0.43188E+00	-0.29809E+00	0.49012E+00
* 1683 *	0.43188E+00	-0.29809E+00	0.49012E+00
* 1684 *	-0.43188E+00	0.29809E+00	0.49012E+00
* 1685 *	0.43188E+00	0.29809E+00	0.49012E+00
* 1686 *	-0.40000E-01	0.50833E+00	0.50833E+00
* 1687 *	0.40000E-01	0.50833E+00	0.50833E+00
* 1688 *	-0.40000E-01	-0.50833E+00	0.50833E+00
* 1689 *	0.40000E-01	-0.50833E+00	0.50833E+00
* 1690 *	-0.43188E+00	0.00000E+00	0.57609E+00
* 1691 *	0.43188E+00	0.00000E+00	0.57609E+00
* 1692 *	-0.26033E+00	0.00000E+00	0.67129E+00
* 1693 *	0.26033E+00	0.00000E+00	0.67129E+00
* 1694 *	0.40000E-01	0.00000E+00	0.71889E+00
* 1695 *	-0.40000E-01	0.00000E+00	0.71889E+00
* 1696 *	0.00000E+00	0.00000E+00	0.72000E+00

ELEMENTS

HEXA2OP	MAVART8D	4
* 1*	1 3 12 14 27 29 38 40 2 8 9 13 19 &	
	20 23 24 28 34 35 39	
HEXA2OP	MAVART8D	5
* 2*	3 5 14 16 29 31 40 42 4 9 10 15 20 &	
	21 24 25 30 35 36 41	
HEXA2OP	MAVART8D	6
* 3*	5 7 16 18 31 33 42 44 6 10 11 17 21 &	
	22 25 26 32 36 37 43	
HEXA2OP	MAVART8D	4
* 4*	12 14 49 51 38 40 64 66 13 45 46 50 23 &	
	24 56 57 39 60 61 65	
HEXA2OP	MAVART8D	5
* 5*	14 16 51 53 40 42 66 68 15 46 47 52 24 &	
	25 57 58 41 61 62 67	
HEXA2OP	MAVART8D	6
* 6*	16 18 53 55 42 44 68 70 17 47 48 54 25 &	
	26 58 59 43 62 63 69	
HEXA2OP	MAVART8D	7
* 7*	7 72 18 81 33 93 44 102 71 11 77 80 22 &	
	86 26 89 92 37 98 101	
HEXA2OP	MAVART8D	8
* 8*	72 74 81 83 93 95 102 104 73 77 78 82 86 &	
	87 89 90 94 98 99 103	
HEXA2OP	MAVART8D	9
* 9*	74 76 83 85 95 97 104 106 75 78 79 84 87 &	
	88 90 91 96 99 100 105	
HEXA2OP	MAVART8D	7
* 10*	18 81 55 111 44 102 70 123 80 48 107 110 26 &	
	89 59 116 101 63 119 122	
HEXA2OP	MAVART8D	8
* 11*	81 83 111 113 102 104 123 125 82 107 108 112 89 &	
	90 116 117 103 119 120 124	
HEXA2OP	MAVART8D	9
* 12*	83 85 113 115 104 106 125 127 84 108 109 114 90 &	
	91 117 118 105 120 121 126	
HEXA2OP	MAVART8D	10
* 13*	76 129 85 138 97 150 106 159 128 79 134 137 88 &	
	143 91 146 149 100 155 158	
HEXA2OP	MAVART8D	11
* 14*	129 131 138 140 150 152 159 161 130 134 135 139 143 &	
	144 146 147 151 155 156 160	
HEXA2OP	MAVART8D	12
* 15*	131 133 140 142 152 154 161 163 132 135 136 141 144 &	
	145 147 148 153 156 157 162	
HEXA2OP	MAVART8D	10
* 16*	85 138 115 168 106 159 127 180 137 109 164 167 91 &	
	146 118 173 158 121 176 179	
HEXA2OP	MAVART8D	11
* 17*	138 140 168 170 159 161 180 182 139 164 165 169 146 &	
	147 173 174 160 176 177 181	
HEXA2OP	MAVART8D	12

* 18*	140	142	170	172	161	163	182	184	141	165	166	171	147	&
	148	174	175	162	177	178	183							
HEXA20P	MAVART8D	13												
* 19*	133	186	142	193	154	202	163	209	185	136	190	192	145	&
	197	148	199	201	157	206	208							
HEXA20P	MAVART8D	14												
* 20*	186	188	193	195	202	204	209	211	187	190	191	194	197	&
	198	199	200	203	206	207	210							
HEXA20P	MAVART8D	15												
* 21*	188	1	195	12	204	27	211	38	189	191	8	196	198	&
	19	200	23	205	207	34	212							
HEXA20P	MAVART8D	13												
* 22*	142	193	172	216	163	209	184	225	192	166	213	215	148	&
	199	175	220	208	178	222	224							
HEXA20P	MAVART8D	14												
* 23*	193	195	216	218	209	211	225	227	194	213	214	217	199	&
	200	220	221	210	222	223	226							
HEXA20P	MAVART8D	15												
* 24*	195	12	218	49	211	38	227	64	196	214	45	219	200	&
	23	221	56	212	223	60	228							
SHEL06C	ST4340	1												
* 25*	38	40	235	39	230	229								
* 26*	235	40	237	230	231	236								
* 27*	40	42	237	41	232	231								
* 28*	237	42	239	232	233	238								
* 29*	42	44	239	43	234	233								
* 30*	235	237	244	236	241	240								
* 31*	244	237	246	241	242	245								
* 32*	237	239	246	238	243	242								
* 33*	244	246	249	245	248	247								
* 34*	44	102	239	101	250	234								
* 35*	239	102	256	250	251	255								
* 36*	102	104	256	103	252	251								
* 37*	256	104	258	252	253	257								
* 38*	104	106	258	105	254	253								
* 39*	239	256	246	255	259	243								
* 40*	246	256	263	259	260	262								
* 41*	256	258	263	257	261	260								
* 42*	246	263	249	262	264	248								
* 43*	106	159	258	158	265	254								
* 44*	258	159	271	265	266	270								
* 45*	159	161	271	160	267	266								
* 46*	271	161	273	267	268	272								
* 47*	161	163	273	162	269	268								
* 48*	258	271	263	270	274	261								
* 49*	263	271	278	274	275	277								
* 50*	271	273	278	272	276	275								
* 51*	263	278	249	277	279	264								
* 52*	163	209	273	208	280	269								
* 53*	273	209	285	280	281	284								
* 54*	209	211	285	210	282	281								
* 55*	285	211	235	282	283	286								
* 56*	211	38	235	212	229	283								
* 57*	273	285	278	284	287	276								
* 58*	278	285	244	287	288	289								
* 59*	285	235	244	286	240	288								
* 60*	278	244	249	289	247	279								
* 61*	12	14	296	13	291	290								
* 62*	296	14	298	291	292	297								
* 63*	14	16	298	15	293	292								
* 64*	298	16	300	293	294	299								
* 65*	16	18	300	17	295	294								

* 66*	296	298	305	297	302	301
* 67*	305	298	307	302	303	306
* 68*	298	300	307	299	304	303
* 69*	305	307	310	306	309	308
* 70*	18	81	300	80	311	295
* 71*	300	81	317	311	312	316
* 72*	81	83	317	82	313	312
* 73*	317	83	319	313	314	318
* 74*	83	85	319	84	315	314
* 75*	300	317	307	316	320	304
* 76*	307	317	324	320	321	323
* 77*	317	319	324	318	322	321
* 78*	307	324	310	323	325	309
* 79*	85	138	319	137	326	315
* 80*	319	138	332	326	327	331
* 81*	138	140	332	139	328	327
* 82*	332	140	334	328	329	333
* 83*	140	142	334	141	330	329
* 84*	319	332	324	331	335	322
* 85*	324	332	339	335	336	338
* 86*	332	334	339	333	337	336
* 87*	324	339	310	338	340	325
* 88*	142	193	334	192	341	330
* 89*	334	193	346	341	342	345
* 90*	193	195	346	194	343	342
* 91*	346	195	296	343	344	347
* 92*	195	12	296	196	290	344
* 93*	334	346	339	345	348	337
* 94*	339	346	305	348	349	350
* 95*	346	296	305	347	301	349
* 96*	339	305	310	350	308	340

QUAD08E	FICFIBER	2						
* 97*	1	3	27	29	2	19	20	28
* 98*	3	5	29	31	4	20	21	30
* 99*	5	7	31	33	6	21	22	32
100	7	72	33	93	71	22	86	92
101	72	74	93	95	73	86	87	94
102	74	76	95	97	75	87	88	96
103	76	129	97	150	128	88	143	149
104	129	131	150	152	130	143	144	151
105	131	133	152	154	132	144	145	153
106	133	186	154	202	185	145	197	201
107	186	188	202	204	187	197	198	203
108	188	1	204	27	189	198	19	205

TRIA12I	0											
109	352	370	374	249	246	244	354	364	358	248	245	247
110	374	406	440	244	237	235	384	418	398	241	236	240
111	374	370	406	244	246	237	364	380	384	245	242	241
112	370	436	406	246	239	237	394	414	380	243	238	242
113	440	560	578	235	40	38	474	548	488	230	39	229
114	440	406	560	235	237	40	418	458	474	236	231	230
115	406	566	560	237	42	40	454	584	458	232	41	231
116	406	436	566	237	239	42	414	470	454	238	233	232
117	436	574	566	239	44	42	484	544	470	234	43	233
118	352	372	370	249	263	246	356	362	354	264	262	248
119	370	404	436	246	256	239	378	412	394	259	255	243
120	370	372	404	246	263	256	362	382	378	262	260	259
121	372	438	404	263	258	256	396	416	382	261	257	260
122	436	558	574	239	102	44	468	542	484	250	101	234
123	436	404	558	239	256	102	412	452	468	255	251	250
124	404	568	558	256	104	102	456	582	452	252	103	251
125	404	438	568	256	258	104	416	472	456	257	253	252
126	438	576	568	258	106	104	486	546	472	254	105	253
127	352	376	372	249	278	263	360	366	356	279	277	264
128	372	408	438	263	271	258	386	420	396	274	270	261
129	372	376	408	263	278	271	366	390	386	277	275	274
130	376	442	408	278	273	271	400	424	390	276	272	275

131	438	562	576	258	159	106	476	550	486	265	158	254
132	438	408	562	258	271	159	420	460	476	270	266	265
133	408	572	562	271	161	159	464	586	460	267	160	266
134	408	442	572	271	273	161	424	480	464	272	268	267
135	442	580	572	273	163	161	490	554	480	269	162	268
136	352	374	376	249	244	278	358	368	360	247	289	279
137	376	410	442	278	285	273	392	426	400	287	284	276
138	376	374	410	278	244	285	368	388	392	289	288	287
139	374	440	410	244	235	285	398	422	388	240	286	288
140	442	564	580	273	209	163	482	556	490	280	208	269
141	442	410	564	273	285	209	426	466	482	284	281	280
142	410	570	564	285	211	209	462	588	466	282	210	281
143	410	440	570	285	235	211	422	478	462	286	283	282
144	440	578	570	235	38	211	448	552	478	229	212	283
145	369	373	351	307	305	310	363	357	353	306	308	309
146	435	405	369	300	298	307	413	379	393	299	303	304
147	369	405	373	307	298	305	379	383	363	303	302	306
148	405	439	373	298	296	305	417	397	383	297	301	302
149	573	565	435	18	16	300	543	469	483	17	294	295
150	435	565	405	300	16	298	469	453	413	294	293	299
151	565	559	405	16	14	298	583	457	453	15	292	293
152	405	559	439	298	14	296	457	473	417	292	291	297
153	559	577	439	14	12	296	547	487	473	13	290	291
154	371	369	351	324	307	310	361	353	355	323	309	325
155	437	403	371	319	317	324	415	381	395	318	321	322
156	371	403	369	324	317	307	381	377	361	321	320	323
157	403	435	369	317	300	307	411	393	377	316	304	320
158	575	567	437	85	83	319	545	471	485	84	314	315
159	437	567	403	319	83	317	471	455	415	314	313	318
160	567	557	403	83	81	317	581	451	455	82	312	313
161	403	557	435	317	81	300	451	467	411	312	311	316
162	557	573	435	81	18	300	541	483	467	80	295	311
163	375	371	351	339	324	310	365	355	359	338	325	340
164	441	407	375	334	332	339	423	389	399	333	336	337
165	375	407	371	339	332	324	389	385	365	336	335	338
166	407	437	371	332	319	324	419	395	385	331	322	335
167	579	571	441	142	140	334	553	479	489	141	329	330
168	441	571	407	334	140	332	479	463	423	329	328	333
169	571	561	407	140	138	332	585	459	463	139	327	328
170	407	561	437	332	138	319	459	475	419	327	326	331
171	561	575	437	138	85	319	549	485	475	137	315	326
172	373	375	351	305	339	310	367	359	357	350	340	308
173	439	409	373	296	346	305	421	387	397	347	349	301
174	373	409	375	305	346	339	387	391	367	349	348	350
175	409	441	375	346	334	339	425	399	391	345	337	348
176	577	569	439	12	195	296	551	477	487	196	344	290
177	439	569	409	296	195	346	477	461	421	344	343	347
178	569	563	409	195	193	346	587	465	461	194	342	343
179	409	563	441	346	193	334	465	481	425	342	341	345
180	563	579	441	193	142	334	555	489	481	192	330	341

QUAD16I	0												
181	560	578	750	766	40	38	29	27	548	658	674	724	39 &
	35	34	28										
182	566	560	748	750	42	40	31	29	584	656	658	772	41 &
	36	35	30										
183	574	566	762	748	44	42	33	31	544	670	656	720	43 &
	37	36	32										
184	558	574	746	762	102	44	93	33	542	654	670	718	101 &
	98	37	92										
185	568	558	752	746	104	102	95	93	582	660	654	770	103 &
	99	98	94										
186	576	568	764	752	106	104	97	95	546	672	660	722	105 &
	100	99	96										
187	562	576	756	764	159	106	150	97	550	664	672	726	158 &
	155	100	149										
188	572	562	758	756	161	159	152	150	586	666	664	774	160 &
	156	155	151										
189	580	572	768	758	163	161	154	152	554	676	666	730	162 &

PRIS15F	EAU	0												
217	578	560	440	814	796	642	548	474	488	650	624	496	784	& 704
218	560	406	440	796	592	642	458	418	474	624	446	496	684	& 612
219	560	566	406	796	802	592	584	454	458	624	630	446	820	& 680
220	566	436	406	802	638	592	470	414	454	630	492	446	696	& 608
221	566	574	436	802	810	638	544	484	470	630	646	492	780	& 710
222	440	406	374	642	592	538	418	384	398	496	446	432	612	& 524

223 406 370 374 592 534 538 380 364 384 446 428 432 520 &
 504 524
 224 406 436 370 592 638 534 414 394 380 446 492 428 608 &
 596 520
 225 376 370 352 538 534 500 364 354 358 432 428 402 504 &
 510 514
 226 574 558 436 810 794 638 542 468 484 646 622 492 778 &
 694 710
 227 558 404 436 794 590 638 452 412 468 622 444 492 678 &
 606 694
 228 558 568 404 794 804 590 582 456 452 622 632 444 818 &
 682 678
 229 568 438 404 804 640 590 472 416 456 632 494 444 702 &
 610 682
 230 568 576 438 804 812 640 546 486 472 632 648 494 782 &
 712 702
 231 436 404 370 638 590 534 412 378 394 492 444 428 606 &
 518 598
 232 404 372 370 590 536 534 382 362 378 444 430 428 522 &
 502 518
 233 404 438 372 590 640 536 416 396 382 444 494 430 610 &
 600 522
 234 370 372 352 534 536 500 362 356 354 428 430 402 502 &
 512 510
 235 576 562 438 812 798 640 550 476 486 648 626 494 786 &
 706 712
 236 562 408 438 798 594 640 460 420 476 626 448 494 686 &
 614 706
 237 562 572 408 798 808 594 586 464 460 626 636 448 822 &
 690 686
 238 572 442 408 808 644 594 480 424 464 636 498 448 698 &
 618 690
 239 572 580 442 808 816 644 554 490 480 636 652 498 790 &
 716 698
 240 438 408 372 640 594 536 420 386 396 494 448 430 614 &
 526 600
 241 408 376 372 594 540 536 390 366 386 448 434 430 530 &
 506 526
 242 408 442 376 594 644 540 424 400 390 448 498 434 618 &
 604 530
 243 372 376 352 536 540 500 366 360 356 430 434 402 506 &
 516 512
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